

## Appendix C - Overview and Results of LPG Testing Programs

### A. LPG Emission Tests

Studies have been conducted to evaluate the impact of varying LPG quality on motor vehicle exhaust emissions. Three studies include the LPG Task Group test program, the WPGA test program, and the ARCO emission tests.

The LPG Task Group test program is the 1998 test program coordinated by staff with a LPG Task Group established by the ARB to oversee the project. The task group consists of representatives from refiners, engine makers, automakers, LPG marketers, and government agencies. The test program was initiated during the 1998 rulemaking to amend the motor vehicle LPG specifications. Emission tests were performed for both heavy duty and light duty vehicles on six different LPG fuel quality.

The WPGA study was sponsored by the WPGA in support of its 1996 petition to delay the 5 volume percent propene limit. Emission tests were performed on light duty dual fuel (LPG and gasoline) vehicles on indolene (Federal certification gasoline) and seven LPGs blends.

ARCO, with several co-investigators, conducted three emission tests on various propane/butane mixtures. Two of the tests, published in 1995, were laboratory studies on a light duty vehicle converted to LPG. The third study, published in 1998, was an in-use vehicle study (during the course of operation) on three medium-duty, LPG-converted transit vehicles.

#### 1. Summary of Estimated Emission Effects of LPG Containing 10 Volume Percent Propene on Individual Vehicle

Table C-1 summarizes information from the three studies about the potential effects of propene and butane content on emissions. The LPG Task Group and the WPGA studies show that the 10 volume percent propene fuel resulted in a small increased (less than 10 percent) in NO<sub>x</sub> emissions in relation to the 5 volume percent propene fuel. The ARCO data indicate that for some LPG vehicles, emissions of hydrocarbons, CO, and OFP may increase slightly and NO<sub>x</sub> may decrease slightly at butane content of about 5 volume percent which is the current limit for butane. Detail discussion of the three studies are presented in the 1998 report, entitled, *Proposed Amendment to the Specifications for LPG used in Motor Vehicles*<sup>1,2</sup>.

**Table C-1: Estimates of Emission Effects in LPG Vehicles --**

**10% Propene and 5% Butane Fuel vs. 4% Propene and 2.0% Butane Fuel**

**(percent change)**

<i>Data Source</i>	<i>NMHC or THC</i>	<i>NOx</i>	<i>CO</i>	<i>Ozone-Forming Potential</i>
Task Group HDV tests (Cummins Engine)	-18%	9%	6%	6%
Task Group LDV tests (Ford F-150)	-9%	-6%	1%	3%
WPGA LDV tests*	0	9%	2%	15%
ARCO LDV tests (butane effect, only)	small increase	small decrease	small increase	small increase
ARCO MDV tests (butane effect, only)	0	0	0	very small increase

\* per ARB staff's regression analysis

2. Analysis of Emission Data from LPG containing Greater than 10 Volume  
Percent Propene on Heavy Duty Engine

Bobtails are LPG delivery trucks capable of fueling on the cargo fuel. Bobtails have been operating on commercial LPG. Commercial LPG fuel could contain from 15 to 30 volume percent propene in the summer months and could be as high as 60 volume percent propene during the winter months<sup>3</sup>. Of the three studies discussed above, only the Task Group study evaluated heavy duty engine on varying propene content as high as 21 percent. Thus, test data were re-evaluated to determine the emission effects of heavy-duty vehicle operating on LPG containing greater than 10 volume percent propene content.

Of the fuels selected by the Task Group, only two test fuels contain greater than 10 percent propene content. Table C-2 describes the two fuels and the base fuel which meets the current specifications of 10 volume percent propene or less and 5 volume percent butane or less. The fuels were tested in a Cummins B5.9 medium heavy-duty LPG engine

**Table C-2: ARB/Task Group Test Fuels**

Fuel	Propene, vol%	Butane, vol%*	Octane # **
Base	9.8	5.0	101.2
1	14.6	5.0	100.2
2	21.3	1.6	---

\* Mean of all measurements

\*\* (R+M)/2

The top half of Table C-3 shows, for the Cummins engine tests, the average emissions from the base fuel and from test fuels 1 and 2. The bottom half of the table shows the same results as percent changes relative to the base fuel average. Linear drift was seen for NO<sub>x</sub> emissions, therefore the adjusted NO<sub>x</sub> emissions are shown in the table. Emissions increased slightly for NO<sub>x</sub> from the beginning to the end of the test program. The emissions drift effect (as fit by a linear model) was statistically significant above a 90 percent confidence level but did not change the results significantly. The analysis and a graphical representation of the data for NO<sub>x</sub> is presented in the 1998 report.

**Table C-3: Average Results for Cummins Engine**

Fuel	Propene	Butane	NMHC	THC	CO	NO <sub>x</sub> *	NMOG	OFP
<b>Actual Emissions, grams/bhp-hr</b>								
Base	9.8	5.0	.670	.702	.407	3.18 (3.19)	.689	1.14
1	14.6	5.0	.636	.670	.489	3.26 (3.24)	.849	1.34
2	21.3	1.6	.594	.623	.324	3.63 (3.56)	.518	1.07
<b>Changes Relative to 10% Propene Fuel</b>								
1	14.6	5.0	-5%	-5%	<b>20%</b>	<b>3%</b> ( <b>2%</b> )	<b>23%</b>	<b>18%</b>
2	21.3	1.6	-11%	-11%	-20%	<b>14%</b> ( <b>12%</b> )	-25%	-6%

\* Numbers in ( ) are adjusted for emissions drift effects.

As shown from the table, increasing the propene and butane contents of the LPG blends (fuel 1) appeared to decrease hydrocarbon emissions but increased oxides of nitrogen (NO<sub>x</sub>); non-methane organic gas (NMOG); and carbon monoxide (CO) emission, and the ozone-forming potential (OFP) of emissions. However, reducing the butane content to less than 2.5% (fuel 2), as specified in the commercial LPG standard, appeared to only increase NO<sub>x</sub> emissions. As seen from the table, the NO<sub>x</sub> emission increases could be as high as 14 percent more than a 10 volume percent propene fuel.

## B. Performance and Durability Testing

The LPG Task Group test program also collects data regarding engine performance and engine durability associated with different formulations of LPG. Both tests were completed in 1999.

The LPG Task Group engine performance and combustion compared how a Cummins B5.9-195 LPG engine operates on a 10 volume percent propene fuel and on a 5 volume percent propene fuel for various internal temperatures, pressures, voltages, knock, and power. The objective of the tests was to determine if the engine continues to operate within the manufacturer's design limits while using the 10 volume percent propene fuel. The results reported was that in general, engine performance was unaffected by fuel blend. The engine was able to produce full power at each engine speed with both blends of fuel. No detonation was encountered (audibly or visually with an oscilloscope) with either fuel blend.

For the durability portion of the test program, 500-hour full-load dynamometer test was performed on the prototype Cummins B5.9L spark ignition propane engine on 10 volume percent propene fuel. Results show no abnormal wear to the engine.

Other reported performance testing was by Detroit Diesel. Detroit Diesel has reported testing LPG with 9.8 volume percent propene and 2.3 volume percent butane in a Detroit Diesel Series 50 engine for cold-start cranking and idle stability, peak torque and horsepower, and knock sensitivity. The test fuel was compared to a 5 volume percent propene fuel. Operation on the 9.8 volume percent propene fuel was indistinguishable from operation on the 5 volume percent propene fuel, except for greater knock sensitivity at 1500 revolution per minute (rpm) (but not other rpms). The knock sensitivity, measured as the maximum air-charge temperature that did not produce knock, was well within the design value and not expected to be encountered in normal use<sup>1,2</sup>.

- 
- <sup>1</sup> Air Resources Board, Proposed Amendment to the Specifications for LPG Used in Motor Vehicles, October 23, 1998.
- <sup>2</sup> Air Resources Board; "Motor Vehicle LPG Test Program (1997/1998)," <http://www.arb.ca.gov/fuels/altfuels/lpg/mvlpge/mvlpge.htm>.
- <sup>3</sup> Meetings and telephone contacts with individual California refiners, fall and winter 2000